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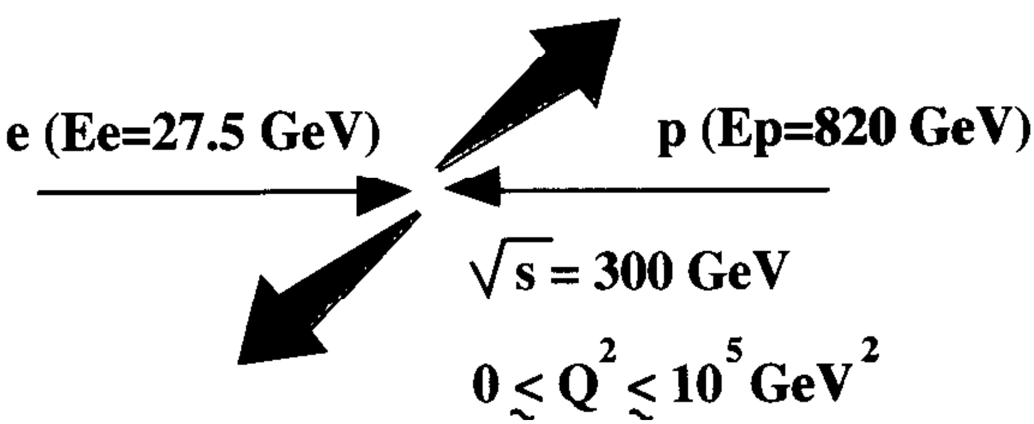
Diffractive Production of Charm and Jets at HERA

ZEUS Collaboration



Diffractive Hard Processes

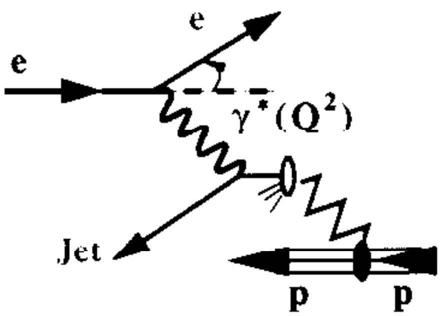
- Diffraction: **successful (and simple!) phenomenological description of soft diffractive reactions in terms of $I\!P$omeron exchange.**

- **Need** to understand diffraction in terms of QCD degrees of freedom, i.e., **quarks and gluons**.

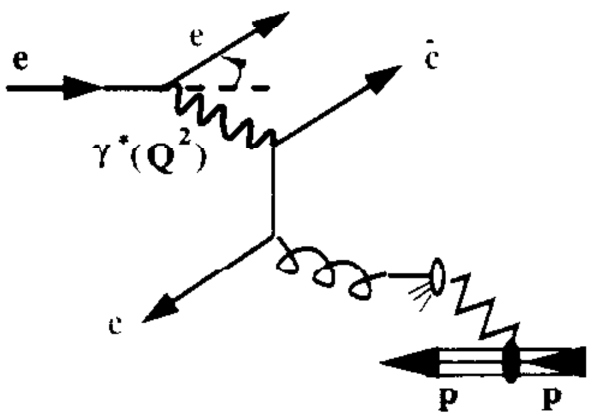
- How? **by probing short distances in diffractive processes. This can be accomplished by measuring** large-E_T lepton, jet, charm ... production.

Diffractive Hard Processes:

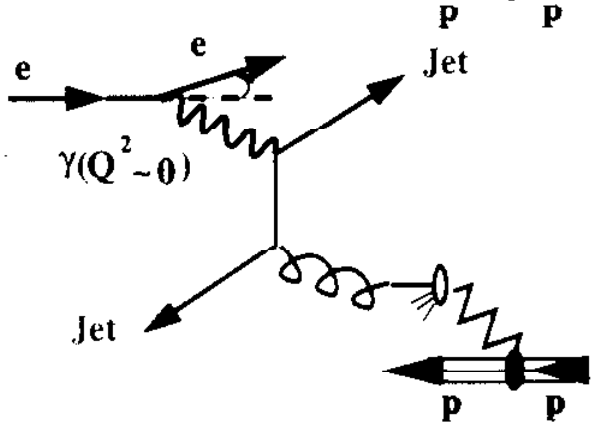
→ HERA provides the best place!!



Deep Inelastic Scattering
at $Q^2 > 8$ GeV^2



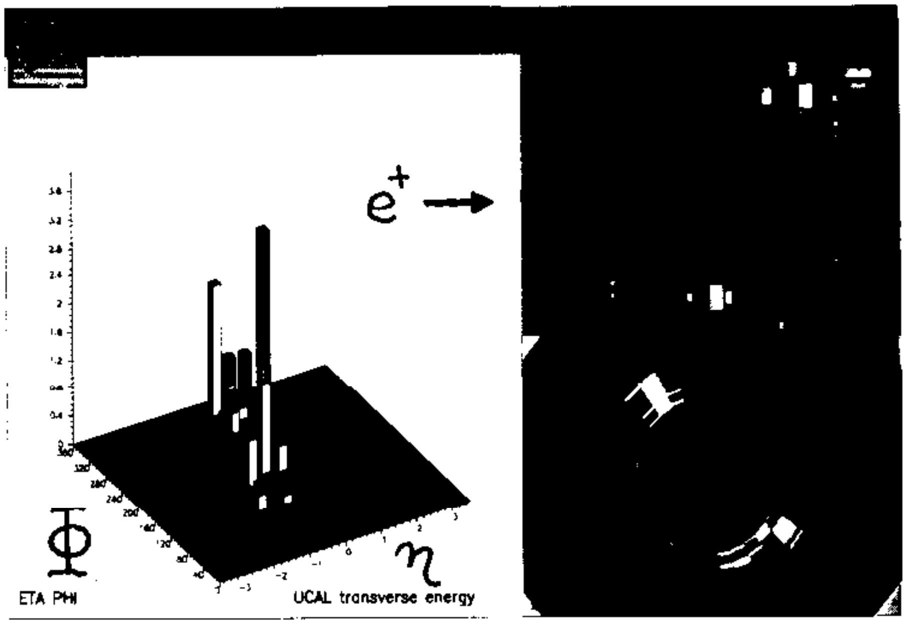
Charm Production in
Deep Inelastic Scattering
at $Q^2 > 10$ GeV^2



Photoproduction
of two Jets
with $E_T^{jet} > 6$ GeV

Hard Scales

- Photoproduction [illegible] a large rapidity gap:

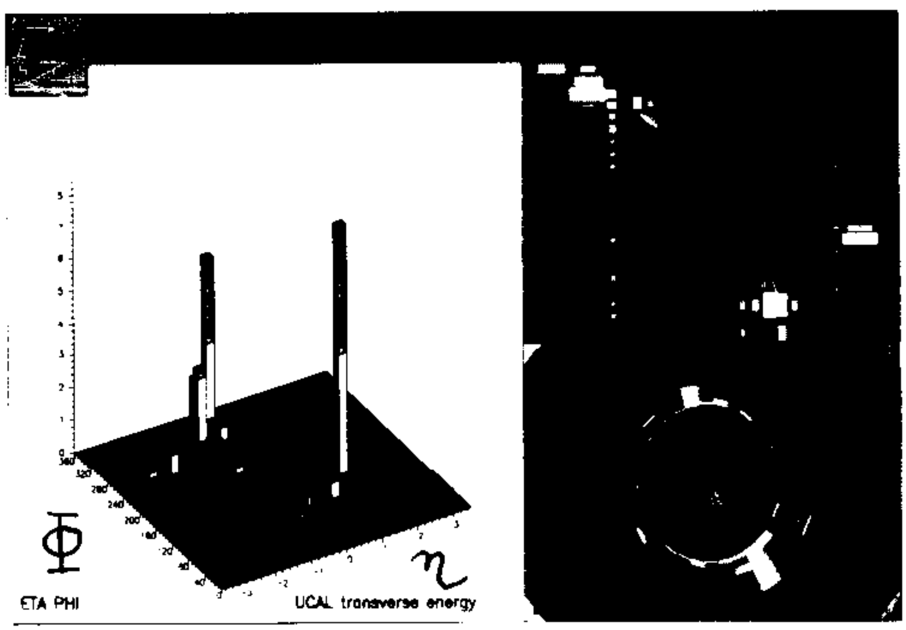


direct candidate

$\eta = -\log \tan \frac{\theta}{2}$

Φ = AZIMUTH

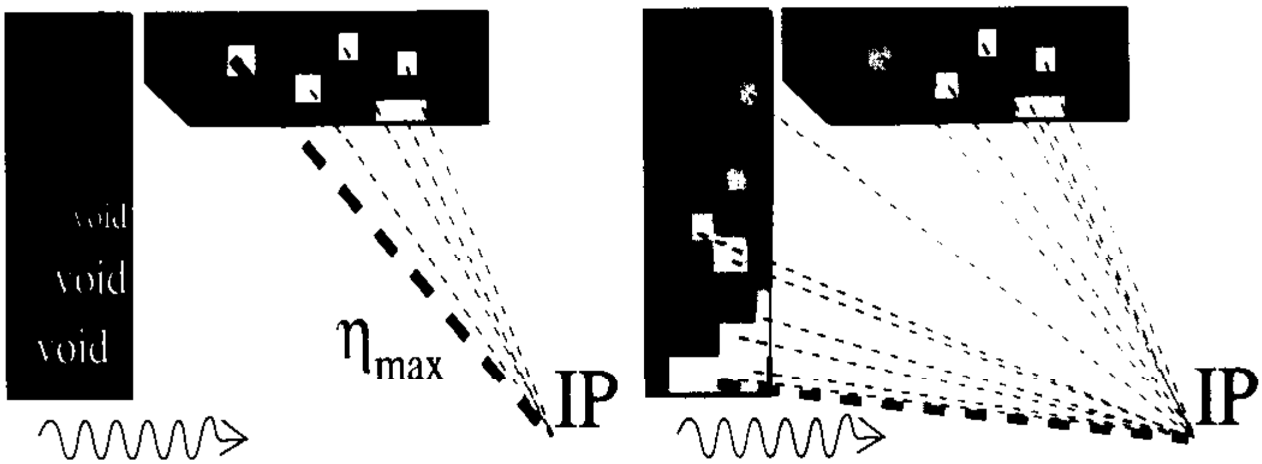
$E_T^{jet_1} = 8.2$ GeV; $E_T^{jet_2} = 6.2$ GeV; $\eta^{jet_1} =$ [illegible]; $\eta^{jet_2} = 0.32$; $x_\gamma^{OBS} = 0.89$



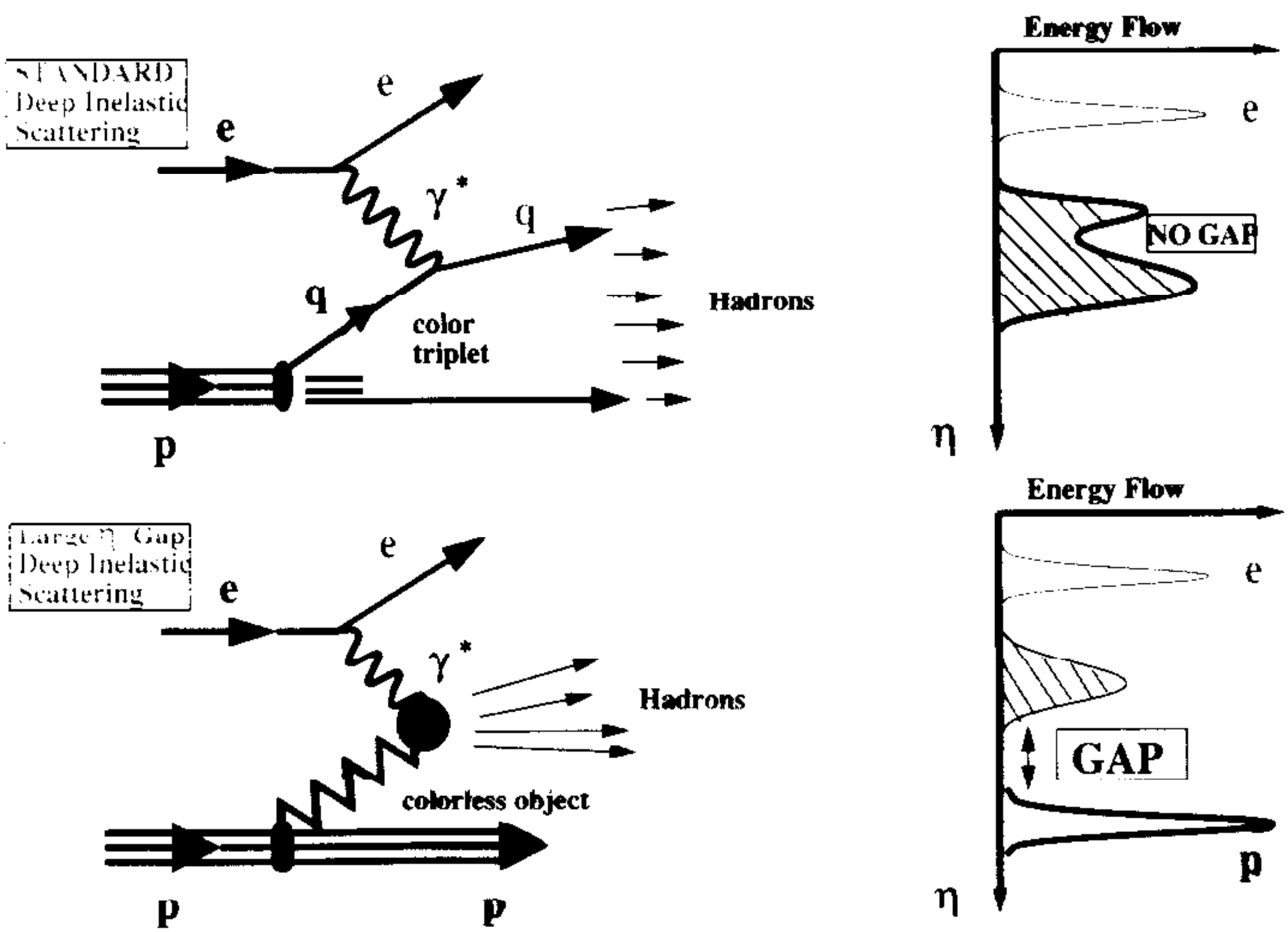
resolved candidate

$E_T^{jet_1} = 14.1$ GeV; $E_T^{jet_2} = 14.0$ GeV; [illegible] $\eta^{jet_2} = -0.35$; $x_\gamma^{OBS} = 0.65$

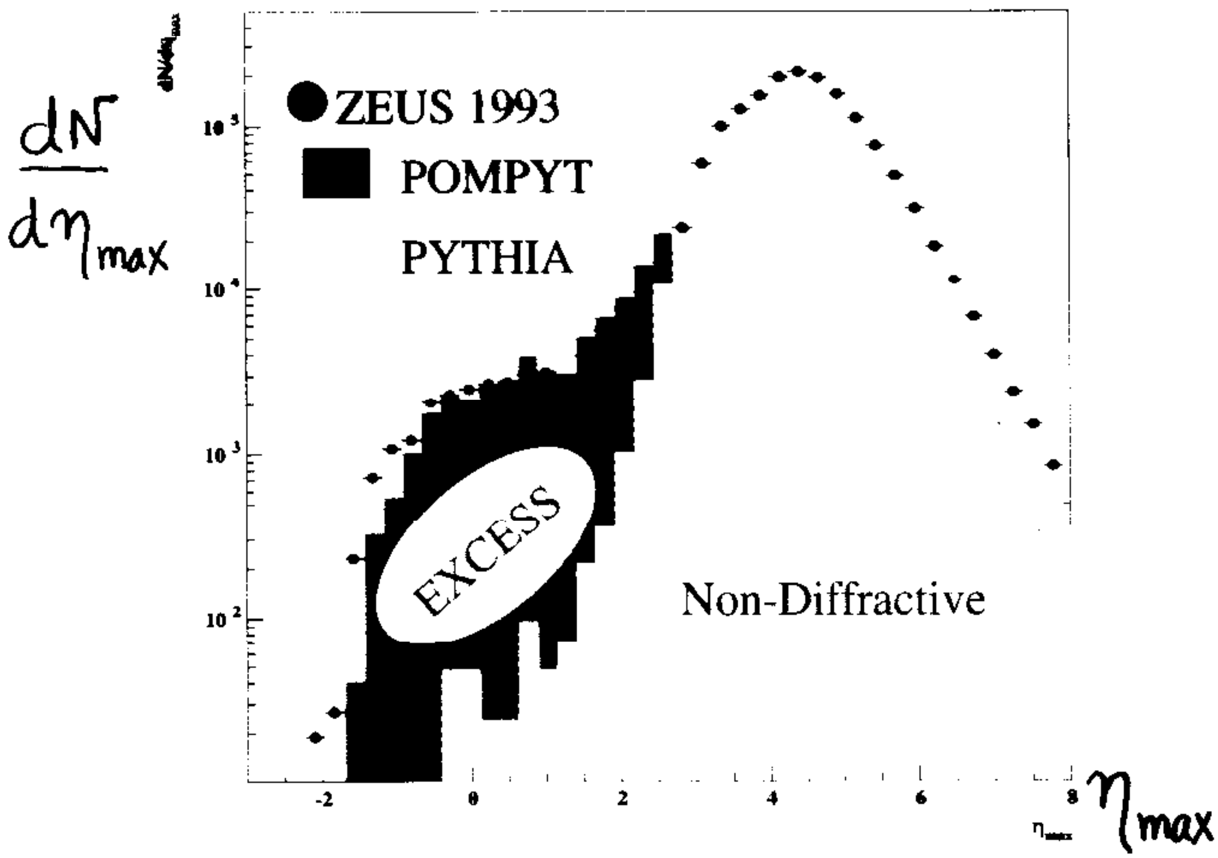
η_{max}: RAPIDITY GAP



OBSERVED RAPIDITY GAP: $\Delta\eta^{obs}_{GAP} = 4.3 - \eta_{max}$



Observation of Diffractive High-E_T Photoproduction:



- **Rate for** Large-Rapidity-Gap **events in Deep Inelastic Scattering and High-E_T Photoproduction** Larger (≥ 10) **than expectations from Standard non-diffractive Monte Carlo's.**

- The characteristics of the **Large-Rapidity-Gap** events (W, Q^2, M_X) suggested a diffractive production mechanism mediated by $I\!P$omeron exchange and pointed to a leading twist contribution.

Inclusive Measurement of Diffractive Deep Inelastic Scattering

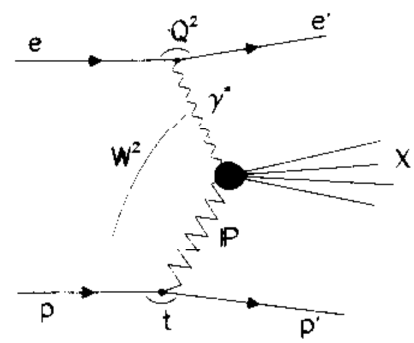
$e(k) + p(P) \to e'(k') + p(P') + \text{anything}$

$\boxed{\text{KINEMATICS:}}$ **4 VARIABLES**

$$\boxed{x = \frac{Q^2}{2P.q};\ Q^2 = -q^2 = -(k-k')^2;\ x_{I\!P} = \frac{(P-P').q}{P.q};\ t = (P-P')^2}$$

$$\beta \equiv \frac{x}{x_{I\!P}}$$

Longitudinal Momentum of $I\!P$ carried by struck parton



Extraction of $F_2^{D(3)}(\beta, Q^2, x_{I\!P})$ (integrated over t) via

$$\frac{d^3\sigma_{ep}(diff)}{d\beta dQ^2 dx_{I\!P}} = \frac{2\pi\alpha^2}{\beta Q^4}[1 + (1-y)^2] F_2^{D(3)}(\beta, Q^2, x_{I\!P})$$

The results are consistent with factorization

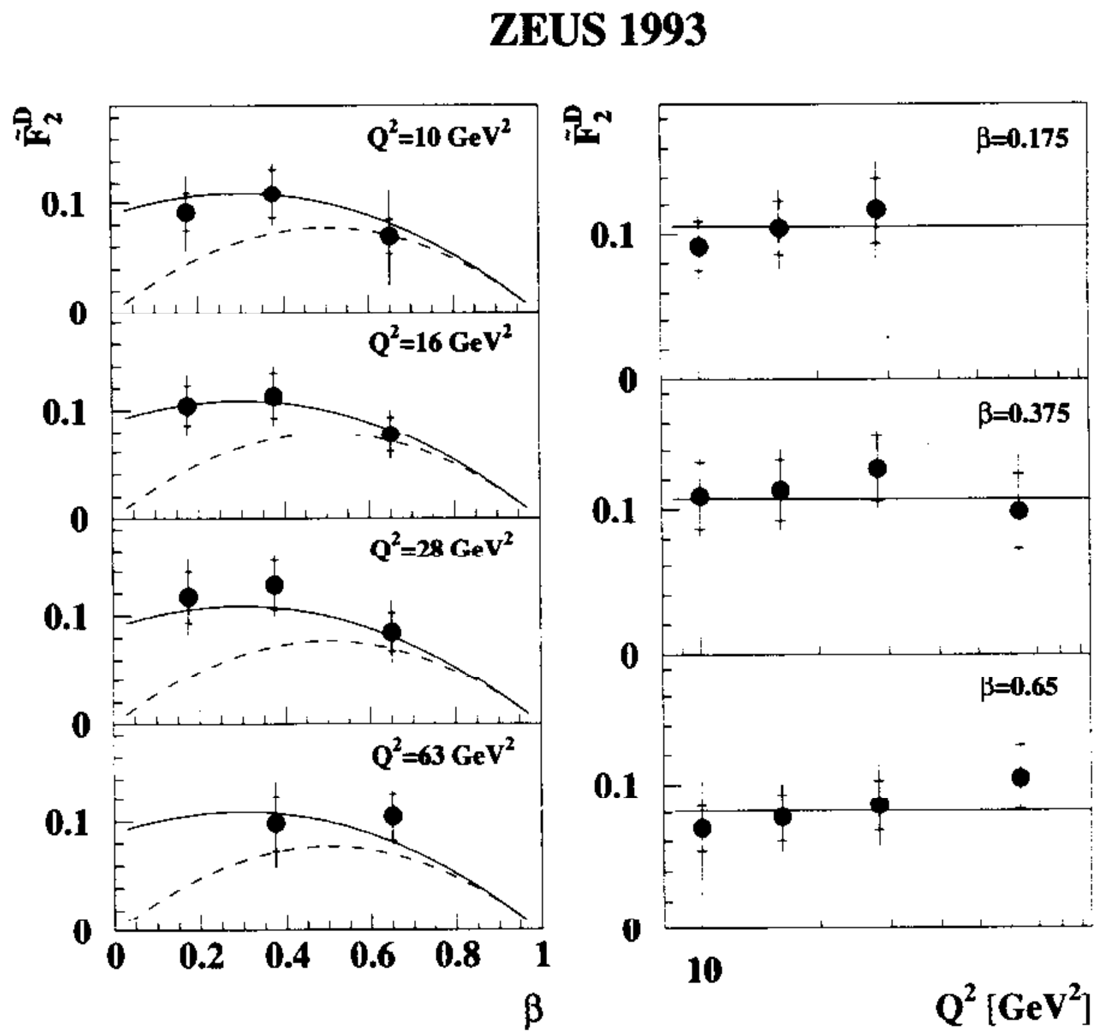
$$F_2^{D(3)}(\beta, Q^2, x_{I\!P}) = \frac{1}{x_{I\!P}^a} f(\beta, Q^2)$$

in the measured range: $8 < Q^2 < 100$ GeV^2;

$0.1 < \beta < 0.8;\ 6.3 \cdot 10^{-4} < x_{I\!P} < 10^{-2}$

Diffractive Structure Function $\tilde{F}_2^D(\beta, Q^2)$

$$\tilde{F}_2^D(\beta, Q^2) \equiv \int_{6.3\cdot 10^{-4}}^{0.01} dx_{I\!P} F_2^{D(3)}(\beta, Q^2, x_{I\!P})$$



- At fixed Q^2: relatively flat β dependence.
- **At fixed β: approximately independent of Q^2.**

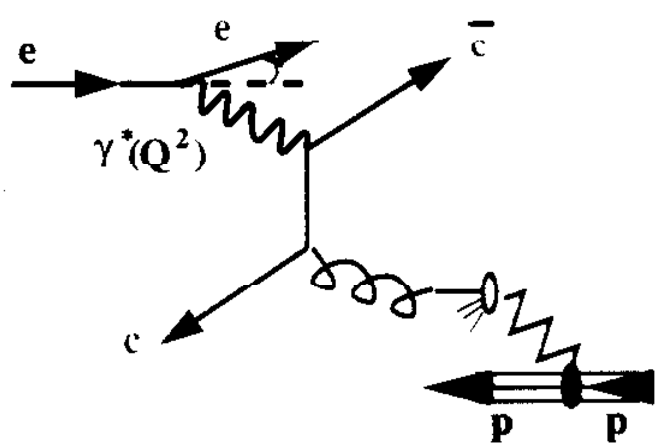
Deep Inelastic Scattering on charged pointlike particles (quarks!) in the colorless object ($I\!P$).

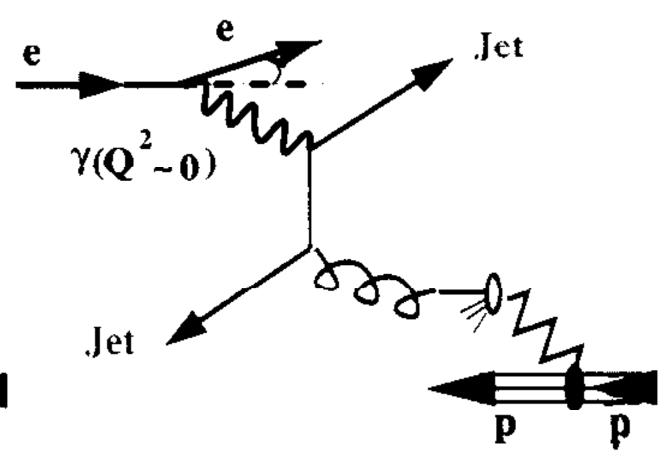
Gluon Content of Colorless Object?

- At leading order QCD, diffractive deep inelastic scattering probes the **quark content of the $I\!P$omeron**.

- Gluons in the $I\!P$omeron? β spectrum? (**Momentum Sum Rule** CANNOT **be applied**).

- **Study of reactions sensitive to gluon content in the $I\!P$omeron:**





Measurement of Dijet Cross Sections in Photoproduction with a Large Rapidity Gap

$$e + p \xrightarrow[Q^2 \sim 0]{} (\text{jet} + \text{jet} + X_r) + e + p$$

$\boxed{\text{KINEMATIC REGION}}$

- $0.2 < y < 0.85$ (134 GeV $< W \equiv \sqrt{s_{\gamma p}} <$ 277 GeV)
- $Q^2 < 4$ GeV^2 (median $Q^2 \approx 10^{-3}$ GeV^2)

$\boxed{\bullet\ \eta_{max} < 1.8}$

$\boxed{\text{JET ALGORITHM}}$

- Cone algorithm in $\eta - \phi$ space with radius $R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 1$ unit based on transverse energies (Snowmass Convention).

- At least two jets with $-1.5 < \eta^{jet} < 1$ and $E_T^{jet} > 6$ GeV for each jet.

ϕ = AZIMUTH ; $\eta = -\log(\tan\theta/2)$

Measured Cross Sections:

$\frac{d\sigma}{d\eta^{jet}}$	$\frac{d\sigma}{dE_T^{jet}}$	$\frac{d\sigma}{dW}$	$\frac{d\sigma}{dx_\gamma}$

- **Diffractive hard photoproduction Monte Carlo, POMPYT, used to correct back to the hadron level.**

- **Non-diffractive background subtracted (using PYTHIA Monte Carlo) and proton dissociation contribution (estimated to be $15 \pm 10\%$) have been subtracted from the data.**

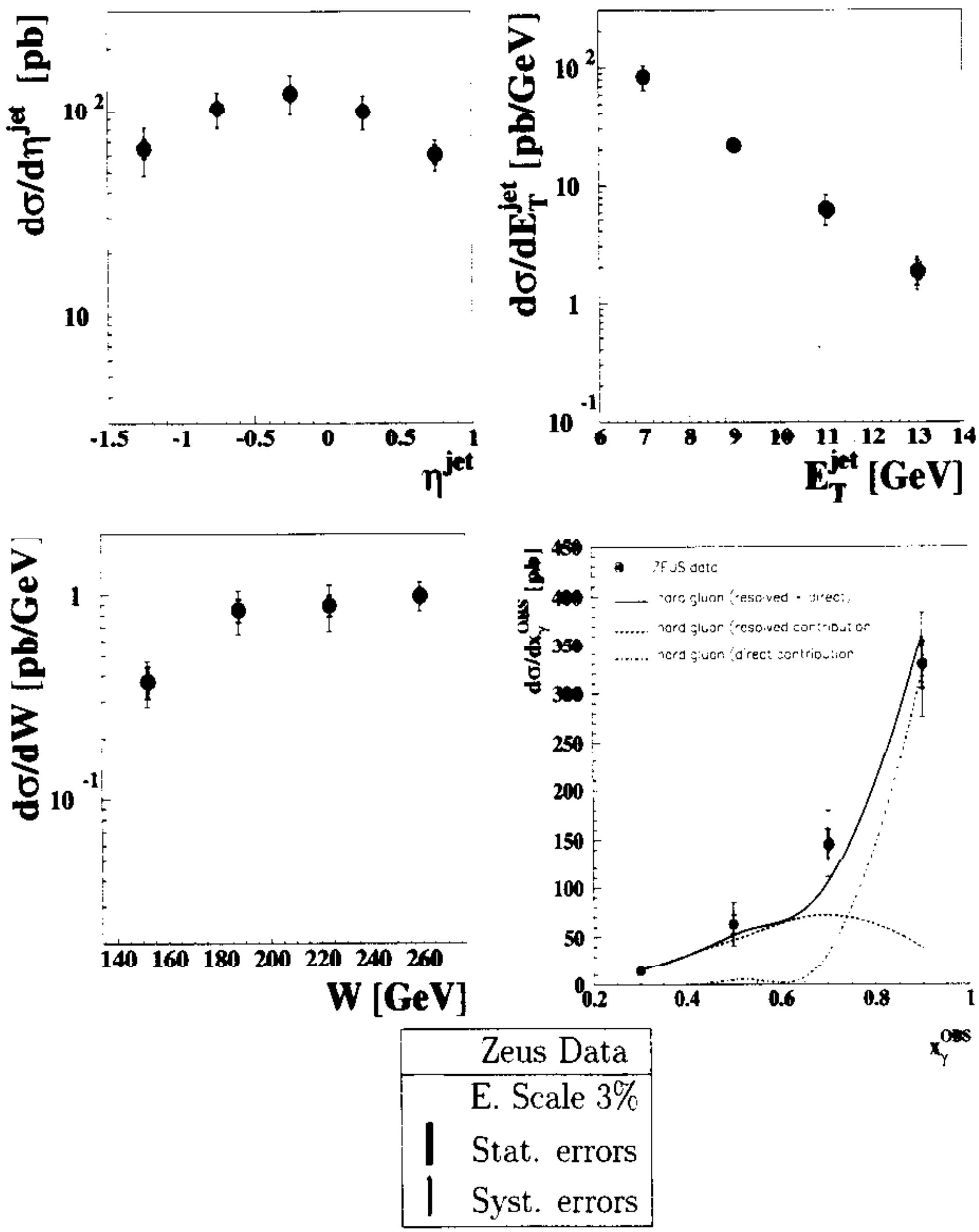
- Improvements with respect to previous measurements (ZEUS 1993):

— ZEUS 1994 Data: 2.6 pb^{-1} (five-fold increase in statistics)

→ **Dijet events: study of resolved and direct contributions.**

Measurement of Dijet Cross Sections in Diffractive Photoproduction

ZEUS 1994 Preliminary



$$x_\gamma^{OBS} = \frac{E_T^{jet_1} e^{-\eta^{jet_1}} + E_T^{jet_2} e^{-\eta^{jet_2}}}{2E_\gamma}$$

Models for Diffractive Hard Scattering

Pioneered by Ingelman, Schlein ('85); Berger, Collins, Soper, Sterman ('87); Donnachie Landshoff ('87); ...

- Based on perturbative QCD and Regge theory.

- **Based on $I\!\!P$omeron exchange (account only for single diffractive).**

- **Generally assume factorization**

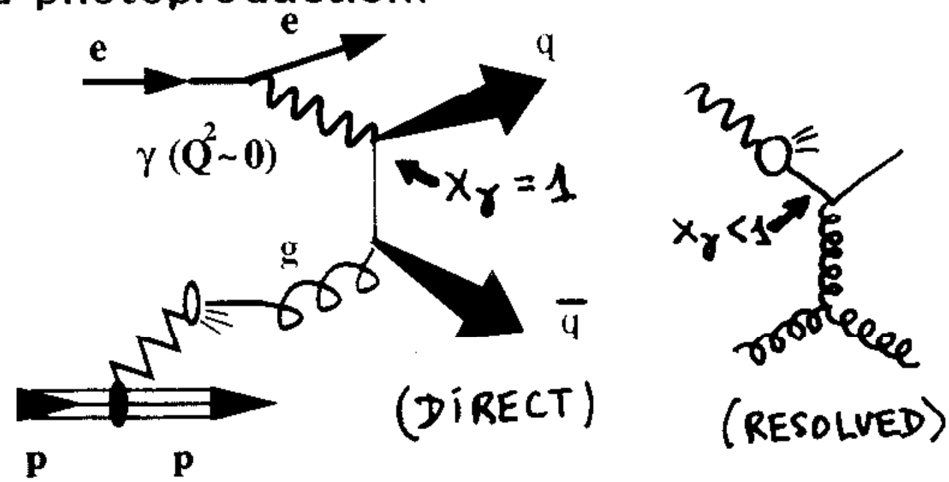
$$f_{I\!\!P}(x_{I\!\!P}, t) * (|\mathrm{MatrixElements}|^2 * f_{i/I\!\!P}(\beta, \mu^2))$$

→ $I\!\!P$omeron flux extracted from data on soft hadronic interactions.

→ Matrix elements computed using perturbative QCD.

→ Parton densities in the $I\!\!P$omeron (universal?).

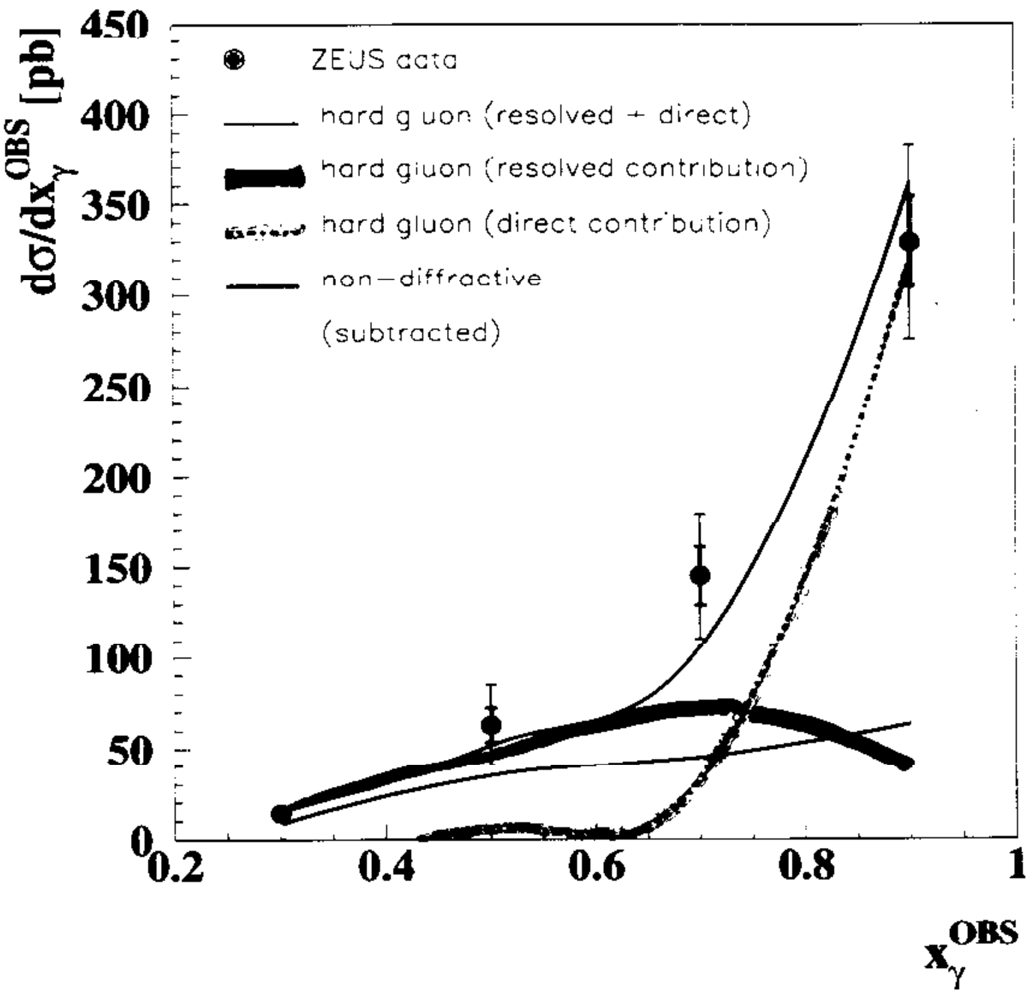
- **POMPYT (Bruni, Ingelman; factorizable model) for diffractive hard photoproduction:**



$$\sigma_{dir}^{jet} = \int dy f_{\gamma/e}(e) \int\int dx_{I\!\!P} dt f_{I\!\!P}(x_{I\!\!P}, t) \cdot$$
$$\sum_i \int d\beta \sum_{jj} \int d\hat{p}_T^2 \frac{d\hat{\sigma}}{d\hat{p}_T^2} f_{i/I\!\!P}(\beta, \mu^2)$$

Evidence for the Resolved and Direct Contributions in Diffractive Hard Photoproduction:

ZEUS 1994 Preliminary



Monte Carlo	Zeus Data
$\beta f_{g/\mathbb{P}}(\beta) \sim \beta(1-\beta)$	
resolved contribution	E. Scale 3%
direct contribution	Stat. errors
non-diffractive	Syst. errors

QCD Fits to ZEUS Diffractive Measurements

- In analogy with the determination of the parton densities in the proton using different processes.

- **Global analysis of ZEUS measurements on $\tilde{F}_2^D$ and dijet cross sections in diffractive photoproduction**

  → $\tilde{F}_2^D$ (DIS) **sensitive to** quark **content of $I\!P$.**

  → $d\sigma/d\eta^{jet}$, ... (photoproduction) **sensitive to** quark and gluon **content of $I\!P$.**

using parton densities in $I\!P$ evolved according to DGLAP equations at NLO-QCD with 3 flavours (CTEQ package).

(suggested by J.C. Collins [illegible] ('95) 3182)

- **Donnachie, Landshoff form for the $I\!P$ flux.**
- **No momentum sum rule applied.**

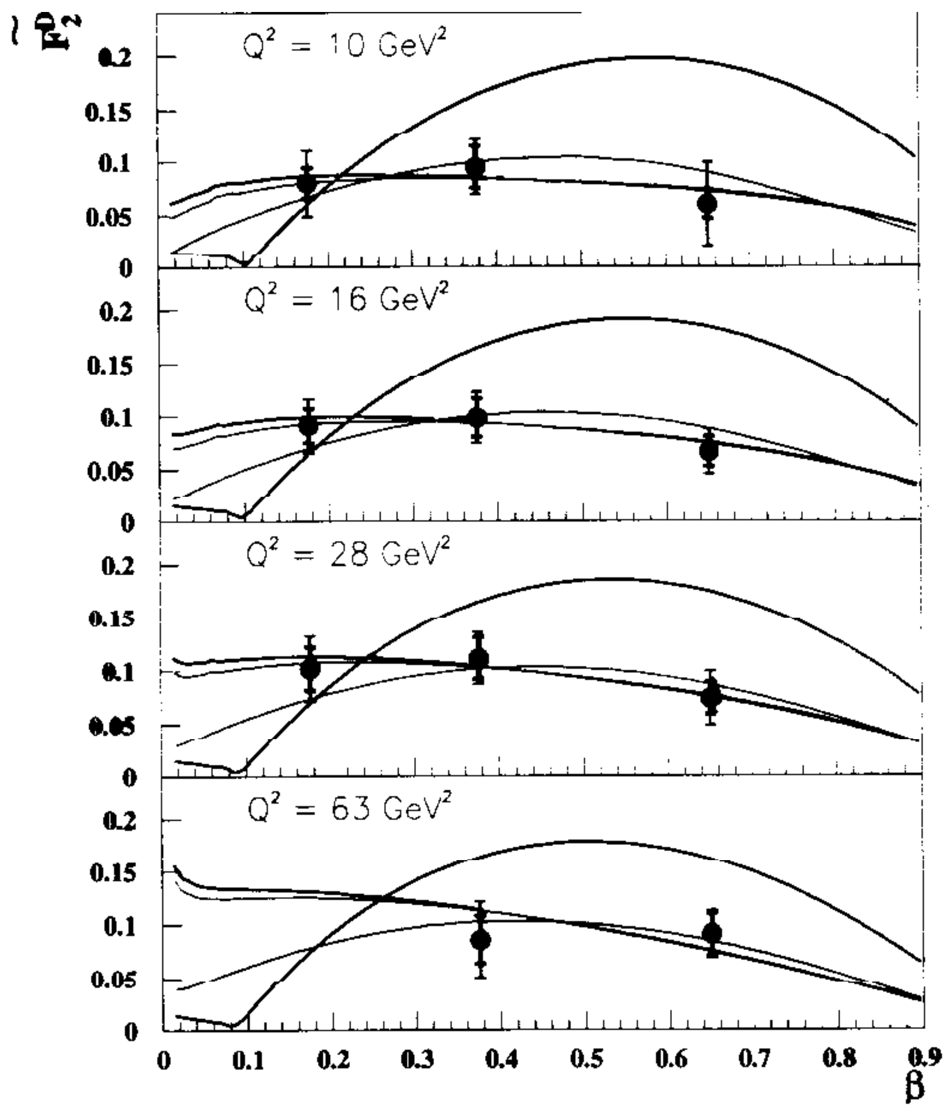
QCD Fits to ZEUS Diffractive Measurements

• Fits to both sets of ZEUS diffractive measurements with different guesses for the initial distributions of $f_{q/I\!P}(\beta, Q_0^2)$ ($q = u$, $\bar{u}$, d, $\bar{d}$) and $f_{g/I\!P}(\beta, Q_0^2)$ at $Q_0^2 = 4$ GeV^2 in order to determine:

→ **relative contribution of quarks and gluons,** $c_g \equiv$ fraction of the momentum of the $I\!P$ carried by partons due to gluons in $I\!P$.

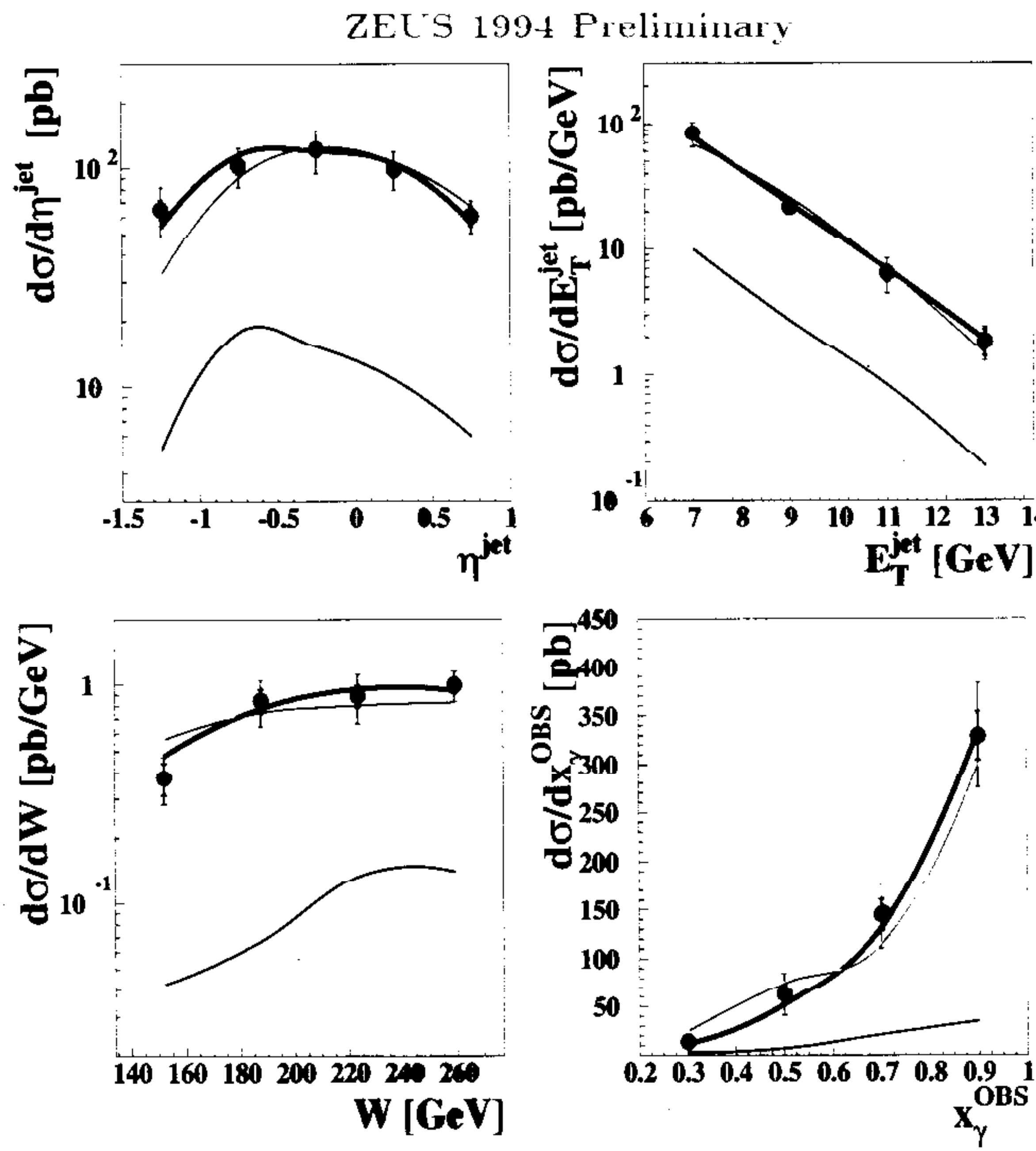
→ **possible contribution from a singular momentum density (peaked at $\beta \sim 1$) component of gluons in $I\!P$.**

Comparison of the fits with ZEUS $\tilde{F}_2^D$ data



	$\beta f_{q/\mathbb{P}}(\beta, Q_0^2)$	$\beta f_{g/\mathbb{P}}(\beta, Q_0^2)$	C_g
▬	$a\beta(1-\beta)+c(1-\beta)^2$		
▬	$a\beta(1-\beta)+c(1-\beta)^2$	$b\beta(1-\beta)$	0.87
▬	$a\beta(1-\beta)$	$b\beta(1-\beta)$	0.87
▬	$a\beta(1-\beta)$	$b\beta^8(1-\beta)^{0.3}$	0.69

Comparison of the Fits with ZEUS Dijet Cross Sections in Diffractive Photoproduction



	$\beta f_{q/I\!P}(\beta,Q_0^2)$	$\beta f_{g/I\!P}(\beta,Q_0^2)$	C_g	Zeus Data
	$a\beta(1-\beta)+c(1-\beta)^2$			
	$a\beta(1-\beta)+c(1-\beta)^2$	$b\beta(1-\beta)$	0.87	E. Scale 3%
	$a\beta(1-\beta)$	$b\beta(1-\beta)$	0.87	Stat. errors
	$a\beta(1-\beta)$	$b\beta^{8}(1-\beta)^{0.3}$	0.69	Syst. errors

Inclusive Measurement of $D^{*\pm}$ Cross Sections in Diffractive Deep Inelastic Scattering

$$e + p \to D^{*\pm} + X + e + p$$

- Using the decay channel:

$$D^{*+} \to D^0 \pi_s^+ \to (K^- \pi^+)\ \pi_s^+ + \text{c.c.}$$

and selecting diffractive candidates with

$$\eta_{max} < 2$$

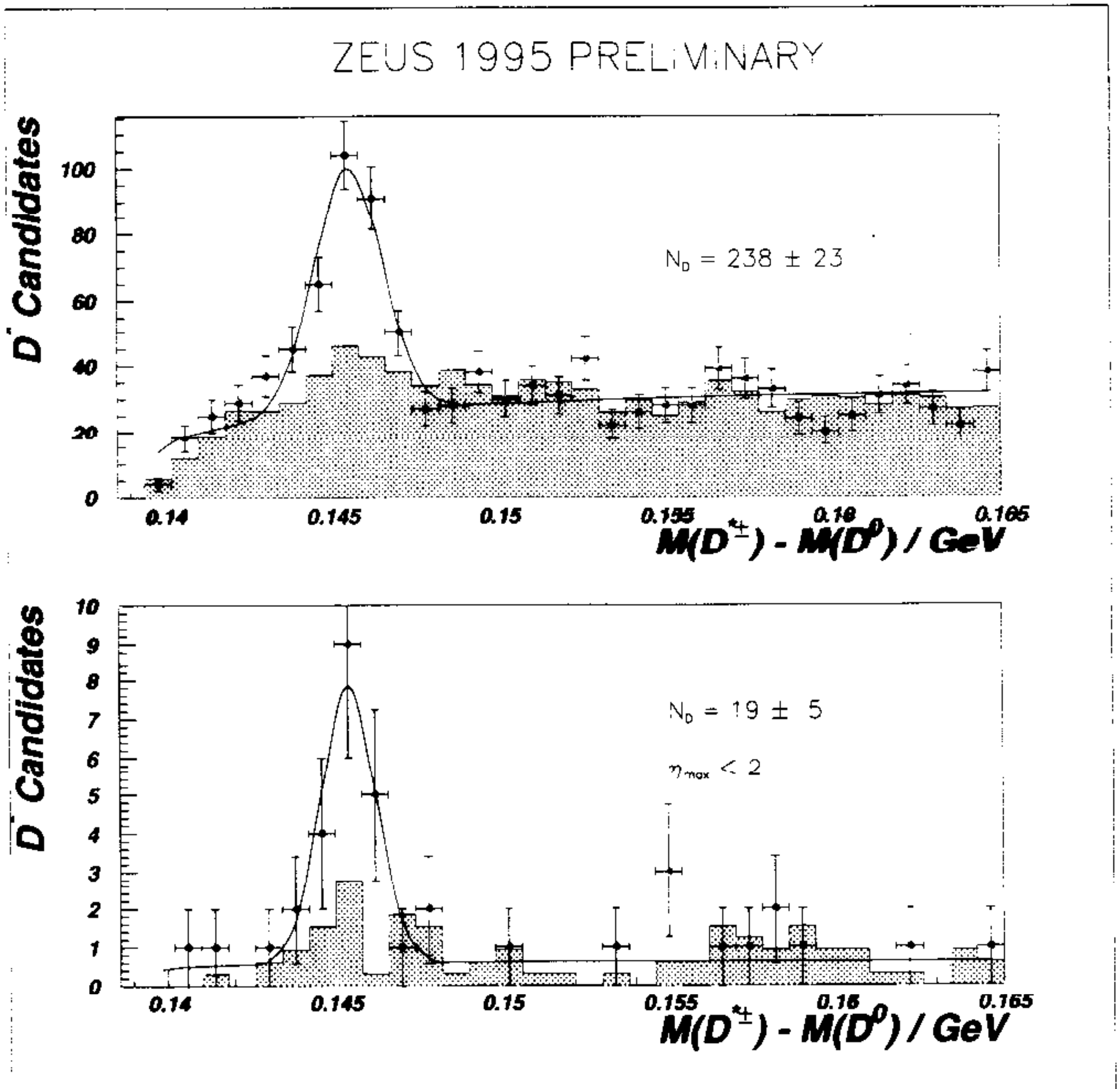
KINEMATIC REGION

- $10\ \text{GeV}^2 < Q^2 < 80\ \text{GeV}^2$
- $0.04 < y < 0.7$

KINEMATIC REGION FOR $D^{*\pm}$

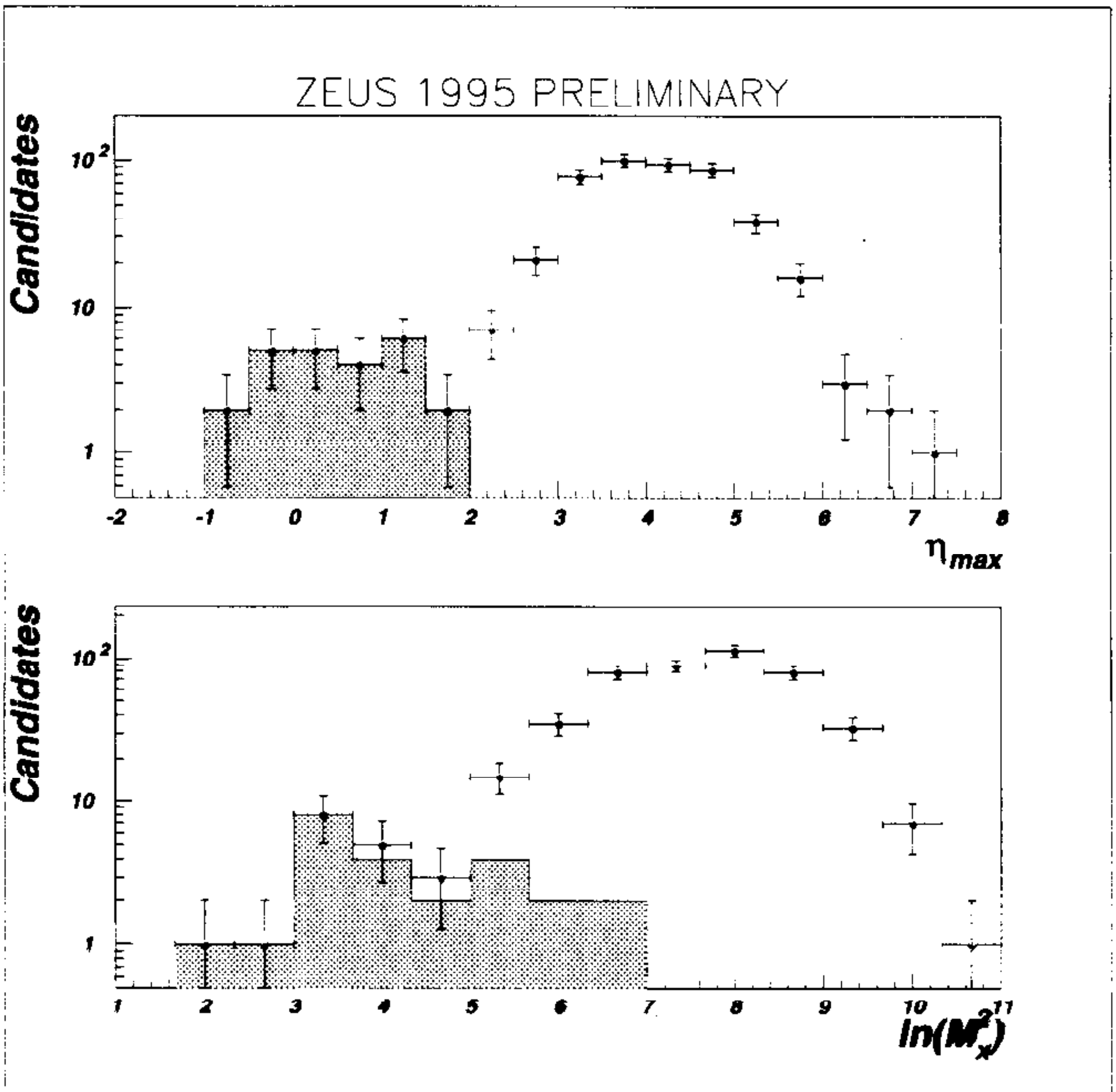
- $p_T(D^{*\pm}) > 1\ \text{GeV}$
- $-1.5 < \eta(D^{*\pm}) < 1.5$

Mass Difference Distribution for Selected Samples



$M((K\pi)\pi_s) - M(K\pi)$

η_{max} and M_X^2 Distributions for Selected Samples



$D^{*\pm}$ Cross Section Measurements

- Diffractive deep inelastic scattering Monte Carlo's, RAPGAP (Jung) and Nikolaev-Zakharov, give a reasonable description of the shapes of the relevant distributions in the diffractive selected sample $\Longrightarrow$ **used for acceptance corrections.**

- **ZEUS 1995 Preliminary**

$\rightarrow$ Cross section for Diffractive $D^{*\pm}$ production:

$$\sigma_{diff}(D^{*\pm}) = 875 \pm 248(\text{stat.}) \ {}^{+395}_{-199}(\text{syst.}) \text{ pb}$$

(including proton dissociation contribution)

$\rightarrow$ Cross section for $D^{*\pm}$ production (no η_{max} cut):

$$\sigma_{all}(D^{*\pm}) = 3.9 \pm 0.4 \text{ (stat. only) nb}$$

- **Approximately 20% of $D^{*\pm}$ in Deep Inelastic Scattering above 10 GeV^2 are diffractively produced.**

Conclusions

- Measurement of Dijet Cross Sections in Diffractive Photoproduction:

  → $d\sigma/dx_{\gamma}^{OBS}$ **shows evidence for** resolved and direct **contributions in diffractive hard processes.**

- **QCD fits to Dijet Cross Sections in Diffractive Photoproduction and Diffractive Structure Function in DIS $\tilde{F}_2^D$:**

  → **a model with DGLAP evolution of the parton densities in the $I\!P$omeron** describes **both sets of measurements**

  → **requiring** hard momentum densities **for both** quarks and gluons **in the $I\!P$omeron and a** large **contribution from** gluons.

- **Measurement of $D^{*\pm}$ Cross Sections in Diffractive Deep Inelastic Scattering:**

$$\sigma_{diff}(D^{*\pm}) = 875 \pm 248(\text{stat.})\,^{+305}_{-199}(\text{syst.})\ \text{pb}$$

→ Approximately 20% of $D^{*\pm}$ in Deep Inelastic Scattering above 10 GeV^2 are diffractively produced.